STATEWIDE CHANGE DETECTION USING MULTITEMPORAL REMOTE SENSING DATA*

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ABSTRACT

The USDA Forest Service and California Department of Forestry and Fire Protection are collaborating on a large-area change detection program using Landsat Thematic Mapper satellite imagery. The program covers the state of California in five separate project areas on a five-year cycle. The goal is to implement a long-term, low cost and high quality monitoring program to identify trends in forest health, assess changes in vegetation extent and composition, and provide data for updating regional vegetation and fire perimeter maps. Landscape changes are detected through two phases. In Phase I a Kauth-Thomas transform is employed to create a landscape-level change map that identifies a continuum of change classes. In Phase II the causes of change are quantified using ancillary information and fieldwork. Project areas are divided by vegetation type for analysis. Causal information about change is collected qualitatively in hardwood rangelands and conifer forests. Field data collected in conifer forests is used to calculate crown closure loss using regression analysis.

INTRODUCTION

As human and natural forces modify the landscape, resource agencies find it increasingly important to monitor and assess these alterations. Changes in vegetation affect wildlife habitat, fire conditions, aesthetic and historical values and ambient air quality. These changes, in turn, influence management and policy decisions. Methods for monitoring vegetation change range from intensive field sampling with plot inventories to extensive analysis of remotely sensed data. While aerial photography can detect change over relatively small areas at reasonable cost, satellite imagery has proven more cost effective for large regions.

The USDA Forest Service's Forest Pest Management Program (FPM) and the California Department of Forestry's (CDF) Fire and Resource Assessment Program (FRAP) and Forest Pest Management Program (CDF-FPM) are conducting a large-area change detection program which covers the state of California over a five-year period. Figure 1 depicts the location and extent of each project area. To date, processing of the Southern Sierra and Northeastern California project areas is complete.

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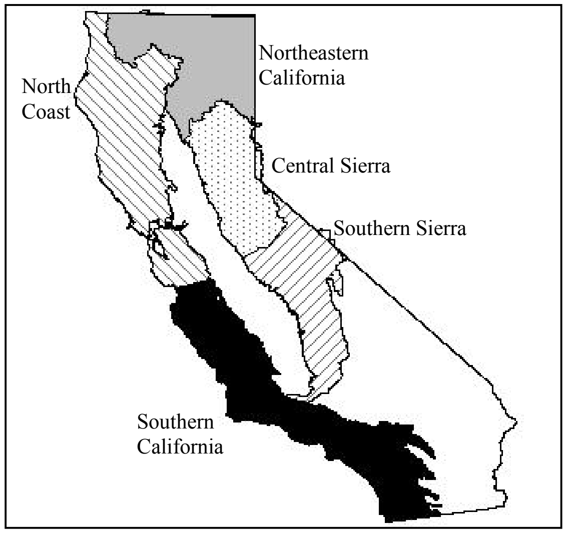

Figure 1. Location and Extent of Project Areas

The goal of this program is to implement a long-term, low cost and high quality monitoring program to identify trends in forest health, assess changes in vegetation extent and composition, and provide data for updating regional vegetation and fire perimeter maps. This program provides current monitoring information across all ownerships and vegetation types represented in California.

Landscape changes are detected through two phases. In Phase I a Multitemporal Kauth-Thomas (MKT) transform (Kauth and Thomas, 1976) is employed to create a landscape-level change map that identifies increases and decreases in vegetation along a continuum of change classes. In Phase II the causes of change are quantified using ancillary information, GIS and fieldwork.

METHODS

PHASE I

When using satellite imagery to detect change, imagery must be co-registered and radiometrically corrected. Image registration ensures that multidate images from the same path and row are registered to each other within one pixel by on-screen identification of common features, such as road intersections. If pixels do not correctly correspond, then changes due to misregistration will occur on the final change map. Differences in atmospheric conditions at the time each image was acquired also affect the pixel values in each image. To correct for these differences, one image must be radiometrically corrected, or normalized, to the other (Collins and Woodcock, 1996). This was accomplished by extracting invariant light (rock outcrops) and dark (water bodies) features from both dates of imagery and applying a regression-based correction on one image (Schott et al., 1988).

Imagery that has been registered, normalized and subset into processing areas is ready for input into the change detection process. Change processing involves image segmentation and MKT transformation. Image segmentation creates regions (polygons based on spectral similarity) from TM bands 3 and 4, and a texture band generated from band 4 (Ryherd and Woodcock, 1990). Texture is a spatial component that enhances subtle edges in the scene over large areas. Generally, regions ranged from 15 to 50 acres. The MKT transform is a linear transformation that reduces several TM bands into brightness, greenness and wetness components. Brightness identifies variation in reflectance, greenness is related to the amount of green vegetation present in the scene and wetness correlates to canopy and soil moisture. The MKT transform is applied to the two dates of imagery that have been merged into a single 12-band image. The result is a change image representing changes in brightness, greenness and wetness values between the two dates.

The final step of the Phase I process is to identify change classes based on the change image. An unsupervised classification of the change image reduces data and aids in image interpretation. This classification results in 50 change classes. Image appearance, photo interpretation, vegetation and topographic maps, GIS coverages and bispectral plots (i.e. greenness vs. wetness) aid in identifying levels of change. Each change class is labeled according to its level of change based on a gradient of change classes from large decreases in vegetation to large increases in vegetation.

PHASE II

Causes of change are quantified using ancillary information, GIS and fieldwork. Vegetation type and ownership are used to stratify the change map. National Forest lands and hardwood rangeland areas are extracted from the change map using a hardwood layer and National Forest vegetation layer as a mask. Areas of known change, primarily those attributable to management activities, are identified using fire and harvest layers. GIS overlay analysis readily attributes these areas of change. Once these areas are identified, 7.5-minute quadrangle-size change maps are plotted for National Forest land, National Park land and hardwood rangelands. Forest resource managers interpret these maps by applying local knowledge regarding sources of change. Similarly, UC Integrated Hardwood Rangeland Management Program (IHRMP) personnel consult private landowners to identify sources of change in hardwood rangelands. Areas without a causal agent identified by the above processes become the focus of field efforts.

Collecting field data on National Forest land and hardwood rangelands further aids in interpreting natural and human-induced change. Fieldwork conducted by IHRMP personnel in hardwood rangelands identified causes of changes in canopy cover due to fire, thinning, harvest, urban development, mortality, regeneration and tree planting. Areas of mortality were identified on National Forest lands and a sample surveyed. Information on mortality and live vegetation was collected at each plot, resulting in the identification and quantification of vegetation change due to conifer mortality.

ANALYSIS OF CHANGE DETECTION DATA

SOUTHERN SIERRA PROJECT AREA ANALYSIS

Areas of classified change are related to cover type by GIS overlay analysis. This process intersects change classes with cover types, thus quantifying the amount of change for each cover type in the project area. Table 1 summarizes acres and percent of classified change by cover type. It is important to note that percentages are based on the areal extent of the cover type within the project area. These numbers indicate a loss in the cover type, but do not necessarily indicate an increase in the same cover type. For example, a fire that occurred in the hardwood cover type during 1990 will appear as an increase in vegetation. The vegetation increase is most likely shrubs, grasses and hardwood regeneration. Generally, each cover type exhibits a higher level of total vegetation increase than total vegetation decrease. The hardwood cover type has one of the highest overall increases in vegetation percentage (15.3%). Even though the conifer cover type has the lowest total percentages in vegetation change, it has the highest number of change acres due to the large extent of conifer forest in the project area. The grass cover type also has a high total increase in vegetation percentage. However, this cover type is subject to scrutiny due to the nature of using TM data. Differences in water moisture between imagery dates can

Table 1. Percent Change by Cover Type

	Hardwood		Conifer		Shrub		Grass		Urban	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Large Decrease	3,068	0.1	10,385	0.2	190	0.0	153	0.0	28	0.3
Moderate Decrease	15,584	0.7	27,392	0.6	2,661	0.5	1,217	0.1	128	1.4
Small Decrease	45,295	2.1	55,522	1.2	8,699	1.8	22,990	1.9	259	2.8
No Change	1,592,853	75.0	3,986,754	86.6	369,599	75.5	953,976	80.1	6,410	69.5
Small Increase	246,301	11.6	140,720	3.1	41,565	8.5	162,992	13.7	1,118	12.1
Moderate Increase	49,997	2.4	63,152	1.4	19,771	4.0	14,481	1.2	492	5.3
Large Increase	5,372	0.3	8,698	0.2	4,287	0.9	7,937	0.7	198	2.1
Non-veg Change	13,805	0.7	9,839	0.2	6,042	1.2	19,806	1.7	193	2.1
Shadow	150,596	7.1	299,471	6.5	36,998	7.6	7,817	0.7	393	4.3

lead to false change classifications and do not necessarily represent a loss or gain in vegetation. Additional field verification is required to verify changes in this cover type. The Urban cover type with high decrease and higher increase in vegetation possibly indicates the removal of natural vegetation and the addition of other vegetation, such as grass (lawns).

This is a broad area analysis conducted with classification based data, thus acreage numbers are not absolute. Classifications are not without error; however, these errors are usually known and for large area analysis, use of these data is appropriate. Also, acreage calculations are based on pixels classified as a particular cover type. Pixels may be classified as a certain hardwood cover type but are actually a mixture of the cover type and another cover type, such as grass.

Once vegetation change has been detected, it is important to determine the causes of these changes. The identification process is useful to verify the accuracy of the change (whether change occurred or not) and in generating a clearer understanding of the variables affecting the landscape. For this project, not all change polygons have been assigned a causal agent, as this is unfeasible given available staff resources, time and money constraints. The cause of many change areas have been identified by GIS analysis, National Forest resource managers and consultation of private landowners within the hardwood rangelands by IHRMP staff. Table 2 summarizes the causes of change in the hardwood rangelands within the project area. Table 3 summarizes the causes of change in the National Forests including the Inyo, Sierra, Sequoia and Stanislaus.

Table 2. Acres of Identified Change in the Hardwood Rangelands

	Large Decrease	Moderate Decrease	Small Decrease		Small Increase	Moderate Increase	Large Increase
Brushing	129	500	1039		0	22	0
Thinning[1]	17	216	546		0	417	17
Harvest	98	1727	2699		0	0	0
Salvage Harvest	2	40	317		0	0	0
Wildfire	1605	9039	4789		0	0	0
Prescribed Burn	76	646	2603		0	0	0
Fuel Break	30	97	146		0	0	0
Mortality	2	3	41		0	0	0
Regeneration	0	0	0		2550	6858	1506
Urban Dev.	43	183	1064		14	97	5
Other Dev.	68	236	685		63	26	8

[1] Thinning detected as vegetation increase occurred prior to the first image date.

Table 3. Acres of Identified Change in the National Forests

	Harvest	Thinning	Site Preparation	Mortality	Wildfire	Prescribed Fire	Fuel Break
Veg. Decrease	7026	283	340	612	14365	2220	121
Veg. Increase	355	0	0	0	88750	673	0

As the tables indicate, various causes of change were identified in the hardwood rangelands and coniferous forest types. Large changes in vegetation cover, such as those caused from harvests and fires, were easily and most frequently detected in these cover types using this change detection process. This is apparent in each change identification table and expected given the marked contrast from vegetative cover to an absence of vegetative cover in TM data. However, smaller canopy alterations, such as thinning, selective harvesting, brushing for defensible space and mortality (which have a lower contrast between different time periods in TM data) were also detectable. This demonstrates an ability of the change detection procedure to detect more subtle changes in vegetation cover.

In the hardwood rangelands, causes of change vary by county. Wildfire and harvesting are the largest causes of change in Calaveras county. In Madera and Kern counties, harvesting and prescribed burning are the major causes of change. Harvesting is the largest source in Mariposa county, and in Tuolumne, Fresno and Tulare counties, wildfire is the largest source of change. Although not the largest cause of change, development has been identified as a source of change in all counties except for Kern. Counties showing the largest amount of change caused by development include Mariposa, Calaveras and Madera. A significant amount of regeneration is identified in Calaveras, Tuolumne and Mariposa counties.

FIRE PERIMETER IDENTIFICATION

Fire perimeter data is routinely recorded and compiled digitally by CDF for planning and resource assessment. To update the fire history database, a preliminary analysis was conducted to test the ability of the change detection data to identify known fires with missing perimeters. This analysis used the Northeastern California change detection data covering the Amador, Eldorado and Nevada, Yuba, Placer CDF ranger units. These units comprise a mixture of vegetation types ranging from coniferous vegetation to grasslands.

Fire perimeters can be detected as vegetation increase or decrease depending on the timing of the fire in relation to the image dates used in the change detection process. Fires occurring between the image dates result in a vegetation decrease where the fire occurred. A vegetation increase is detected when a fire burned prior to the first image date and regeneration is beginning.

To detect fire perimeters, a comparison was made between existing perimeters and the change detection data. While not identical, there is strong agreement between known fire perimeters and the change data. This indicates that in areas where there is no fire perimeter or the existing fire perimeter is of questionable accuracy, the change detection product should be useful in identifying and delineating a new fire perimeter. Further analysis using the CDF Emergency Activity Reporting System (EARS) revealed that most of the fires in the study area with missing perimeters are in grasslands. These perimeters are often not discernable because grassland regeneration occurs very quickly and is not easily detected within the 5-year time frame. Fires occurring in forests, however, have slower regeneration times and are therefore easier to detect.

Using the change detection data to detect fire perimeters in forested areas and oak woodlands was useful and may prove beneficial in detecting fires associated with other woody vegetation. For the two ranger units, most of the large fires with missing perimeters also occurred in the grasslands. The corresponding time intervals for detecting perimeters in the grasslands from the change detection project did not result in the generation of new fire perimeters. This is due to the fact that the change detection project is not intended to detect fires specific to grasslands. The change detection data will provide input to the fire history database updating process for oak woodlands and conifer forests.

SILVICULTURAL SYSTEM IDENTIFICATION

Each year timber harvest plans (THPs) are submitted to the California Department of Forestry and Fire Protection by private timber owners. These are reviewed to ensure compliance with the forest practice rules established by the state of California's Board of Forestry. Once a THP is approved, general information (i.e. THP number, location, county, owner, etc.) about the THP is archived into a digital database. Spatial orientations of the THP boundaries and silvicultural systems are not incorporated into this database. While the THP process ensures conformance with environmental guidelines in the forest practice rules, the spatial effects that different silvicultural methods have on the vegetation cover and landscape at particular sites are difficult to evaluate. Change detection data can potentially provide the data necessary to monitor and evaluate THPs spatially across the landscape.

The objective of this pilot project is to assess the use of change detection data for monitoring THP operations and their outcomes. This is accomplished by evaluating the type and level of silvicultural practices that are detectable by the change detection process. A total of 37 THPs were evaluated for this project. Most THPs are located in the Southern Sierra change detection project area (Fresno, Calaveras and Tuolumne counties). A few are located in the Northeastern California project area (Eldorado county).

There is a general agreement between the boundaries of the THP practices and the change detection data. Some areas fit very well, while others vary in size or shape. A relationship also exists between the type of treatments and the change classes. For example, higher levels of timber removal such as clearcutting are detected primarily as large and moderate vegetation decreases while lower levels of timber removal are detected primarily as moderate and small vegetation decreases or no vegetation change. Table 4 summarizes the acres in each change class for each represented silvicultural treatment.

Table 4. Change Class Distribution Within THPs

	Large Decrease	**Moderate Decrease**	**Small Decrease**	**No Change**
Clearcut	241	637	91	0
Shelterwood Removal	17	27	4	0
Seed Tree, Seed Tree Step	7	62	0	0
Seed Tree, Removal Step	6	22	50	248
Selection	25	487	1485	1136
Commercial Thinning	30	226	564	773
Alternative Prescription[2]	5	105	608	1368
Transition Method[3]	23	176	281	494

Problems did emerge in the detection of the various silvicultural methods. Boundary problems seem to be a combination of the resolution of the change data (30 meters), and the completion status of the THP. Harvesting within the THP was not always completed within the time frame of the change

[2] Modified selective harvests.
[3] Used to create unevenaged stands by individual and small group tree removals.

detection data. The user-defined threshold between no change and small decrease in vegetation has caused some areas of thinning and selective harvests to show up as no change.

This pilot study is promising and the problems associated with the detection of the various silvicultural systems are correctable. Further refinement will produce a means for using the change detection data to monitor and evaluate THPs.

CONCLUSION

This project successfully shows that change detection techniques can be applied to hardwood and coniferous forest environments. Analysis of the change data provides information to assess landscape-level changes in vegetation extent and composition. It also affords information on causal agents that are having the greatest impact throughout a project area.

The change data also benefits existing programs. Incorporating change data into the fire history mapping project enhances the ability to correctly map missing fire perimeters in the hardwood and coniferous vegetation types. Monitoring and evaluating THPs and silvicultural practices using change detection data can also be accomplished. Research is required to define thresholds between change classes representing quantitative changes in canopy reduction and growth.

Although the numbers representing acres of detected change have not been verified by an accuracy assessment, correlations do exist between detected change and various causes such as harvest, fire, development and regeneration. Accuracy assessment procedures are being implemented into future project areas.

Future studies to assess the utility of the change detection data include vegetation map updating, fuels map updating, monitoring and measuring postfire effects and urbanization pressures.

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